TFW-WQ4-91-002

# T/F/W STREAM TEMPERATURE METHOD: USER'S MANUAL

By

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TIMBER/FISH
& WILDLIFE

JUNE 1991

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**Prepared for the**
**T/F/W CMER Water Quality Steering Committee**
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**June 1991**

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TABLE OF CONTENTS

IMPORTANT NOTICE

This manual is for testing the methods outlined herein. While it is encouraged that T/F/W participants review this manual and use it on a trial basis onlv, the methods are not to be used to condition forest practices applications except on a strictly voluntary basis. The initial use of this manual is intended to be in conjunction with the management trials. The model is for use in Washington only. Although studies suggest that Type 4 and 5 streams exhibit similar temperature regimes (Caldwell and others, 1991) this manual is, at this time, only applicable to Type 1-3 streams. All users are encouraged to read the foreword before using the model.

# FOREWORD

The methods described in this rnanual include both a graphical temperature screen for identifying stream temperature categories and a computer model. Although possibly applicable outside of Washington, we caution potential users against their use in other regions because they incorporate climate information specific to this region . For potential users in other areas, we suggest an investigation of the TEMPEST computer model (Adams and Sullivan, 1990). A temperature screen could readily ‘be developed for other regions following validation testing for that region.

Review and the development of this manual was done in coordination with a sub-committee representing members of the T/F/W Field Implementation Committee and the Temperature Work Group. This sub-committee included representatives of Departments of Natural Resources and Ecology, tribes, and industry. A goal of this sub-committee was to provide a bridge from research products to T/F/W applications.

The “TFWTEMP” temperature computer model, its documentation and user’s manual, were developed to be used in the context of timber management in Washington state under the Timber/Fish/Wildlife Agreement. The model authors invite use of, and comments on, this software. We consider this to ‘be shareware, available for T/F/W participants, and not to be sold.

The TFWTEMP model, which incorporates Washington state regional climate data and stream channel characteristics, was written by John E. Tooley. TFWTEMP uses energy balance equations for stream heat exchange developed for the TEMPEST model by Terry Adams, with QuickBASIC code by Steve Washburn, and revisions recommended by Kate Sullivan and Terry Adams. Additional programming was done by Jeffrey Smith, with help screens and user’s manual developed by Kent Doughty, Jean E. Caldwell and Kate Sullivan.

Regional profiles of solar insolation values were developed in part using the U.S. Fish & Wildlife Service, National Ecology Research Center, SSSOLAR computer model (Theurer and others, 1984).

The authors request that users of the model software and the temperature screen give credit when appropriate to the authors and developers. (The correct citation for the research report is “Sullivan, K., J. Tooley, K. Doughty, J.E. Caldwell, and P. Knudsen, 1990. Evaluation of Prediction Models and Characterization of Stream Temperature Regimes in Washington. Washington Dept. of Natural Resources Timber/Fish/Wildlife Report TFW-WQ3-90-006.") All recipient-modified program source code and documentation should acknowledge the appropriate source of the parent computer system and algorithm. Recipients should not represent modified TFWTEMP programs as original products. Rather, reference should be made to the TFWTEMP software and authors, as modified by the recipient.

The model authors and the T/F/W ‘Temperature Work Group, would like to acknowledge that much of the model’s Washington-state specific climate and stream data would not have been available without the data collection efforts, financial support, and patience of a large number of T/F/W co-operators.

# TERMINOLOGY

Two terms which are used interchangeably within this report might be confusing. These terms are “shade” and “canopy closure”. As described in section II, the heat exchange process affecting stream temperature involves both heat gains and losses to the atmosphere. The term “canopy closure” more fully recognizes that the influence of riparian cover and topography is more complex than simply the shadow or “shade” cast by the sun. However, most individuals are more familiar with the concept of shade so that term is favored in this manual. The most appropriate conceptual understanding of riparian cover and topography is to think of it as a screen blocking a portion of the view of the sky.

Please see Appendix B for a glossary of more terms.

# SECTION I INTRODUCTION

## 1.1 TFW Temperature Concerns

The potential effects of forest practices on stream temperature were identified as a major concern during negotiations of the Timber/Fish/Wildlife Agreement of 1987. The direct effects of timber removal on the temperature of larger, fish-bearing streams (types 1-3) were addressed by riparian zone management rules that specified leave tree requirements along streams that were designed, in part, to preserve shading and maintain suitable water temperature. However, several concerns regarding stream temperature in types 1 -3 waters remained partially unresolved at the time of the 1988 T/F/W Agreement. In addition, concerns remained that because vegetation buffers are not ordinarily required for very small streams (type 4 and 5), inadequate temperature protection measures in upstream waters could raise temperature in downstream reaches to adverse levels.

T/F/W identified key management issues to focus for further research efforts, including: (1) criteria for identifying temperature sensitive streams, (2) a method for describing their geographic extent, and (3) a reliable method of predicting water temperature keyed to riparian management.

## 1.2 1988 - 1990 T/F/W Temperature Study

A study was undertaken in 1988 by the Temperature Work Group (TWG) of the Cooperative, Monitoring, and Evaluation (CMER) Committee to develop a method to investigate temperature on a site and basin scale. Members represented the Departments of Ecology and Fisheries, industry, and tribes.

The temperature study was designed to generate information for two primary purposes: data was collected from forest streams extensively (92 sites) throughout the state to develop a stream temperature screening method and intensively at a smaller number of sites (33) to evaluate the predictive capabilities of existing reach and basin temperature models. Study sites represented Type 1-3 streams located in all regions of the state having a variety of riparian shading conditions ranging from mature conifer forest to sites completely open and devoid of shade. Results of this project are reported in Sullivan and others (1990).

## 1.3 Application of this Manual

This manual is based upon the results and recommendations of the above mentioned study. The manual presents a step by step method for determining shade levels necessary to meet the Washington water quality criteria of the state water quality standards.

T/F/W managers likely to use this method include state, private and tribal foresters, fisheries biologists and water quality regulators. The method relies on a graphical temperature screen and a computer model that can be used to predict temperatures within a stream reach. The temperature screen is a simple tool to predict temperature category dependent upon site elevation and stream shading. The temperature screen does not require a computer, while using the computer model requires an IBM-compatible personal computer with a minimum 512K RAM.

The TWG has developed this recommended method to be used in the context of adaptive management, which means that the method is flexible, can be adapted to local needs, and can be changed and updated as further information becomes available. As with all models, predictions and classifications obtained using this method must be interpreted with professional judgement, common sense, and a knowledge of local conditions.

# SECTION II BACKGROUND

## 2.1 A Summary of Important Principles of Forest Stream Heating

The water temperature observed at any location within a stream system reflects a balance between heat input and heat loss. The exchange of heat across the air-water interface is one of the more important factors that govern the temperature of a water body for a given solar Input. The rates of both input and loss of heat are influenced by local environmental factors. Heat input is determined by the amount of direct solar radiation reaching the stream environment which varies daily and seasonally with position of the sun, and with shading by riparian vegetation or topography. Heat loss is largeiy regulated by the difference between air and water temperature. Conduction to the stream ‘bed and groundwater inflow also account for heat loss but this is generally a relatively small percent of the total energy budget during the summer.

As a stream is heated by solar radiation and convection over a daily solar cycle, heat loss from evaporation and radiation back to the sky also increases rapidly. Some stream temperature will always be reached where heat loss balances heat gain and no further change in water temperature occurs with increased energy input. Edinger and others (1968) referred to the water temperature at which heat input just balances heat loss as “equilibrium temperature”. Since most of the energy exchange terms involve air temperature, this factor is very influential in determining the equilibrium stream temperature (Adams and Sullivan, 1990). Air temperature continually changes in response to varying meteorological conditions on a daily and seasonal basis and there is an equilibrium water temperature for each air temperature (Edinger and others 1968). The water temperature is continually driven towards the air temperature with the rate determined by the difference between the two. A useful illustration of this principle is the tendency for both hot and cold water to change to match room temperature.

Importantly, rapid heat loss at high temperatures sets an upper limit to stream temperature relative to air temperature that is independent of stream she. During hot summer days when the temperature differential is greater than this amount, the heat loss from evaporation and radiation losses is also great and additional incoming heat to the water is quickly lost back to the air. Thus each stream has a maximum water temperature observed at a threshold level of air temperature. (When air temperature is lower than the threshold value, water temperature responds to it, but when air temperature rises above this level there will be no increase in the observed water temperature.) We refer to this water temperature as the “maximum equilibrium temperature.”

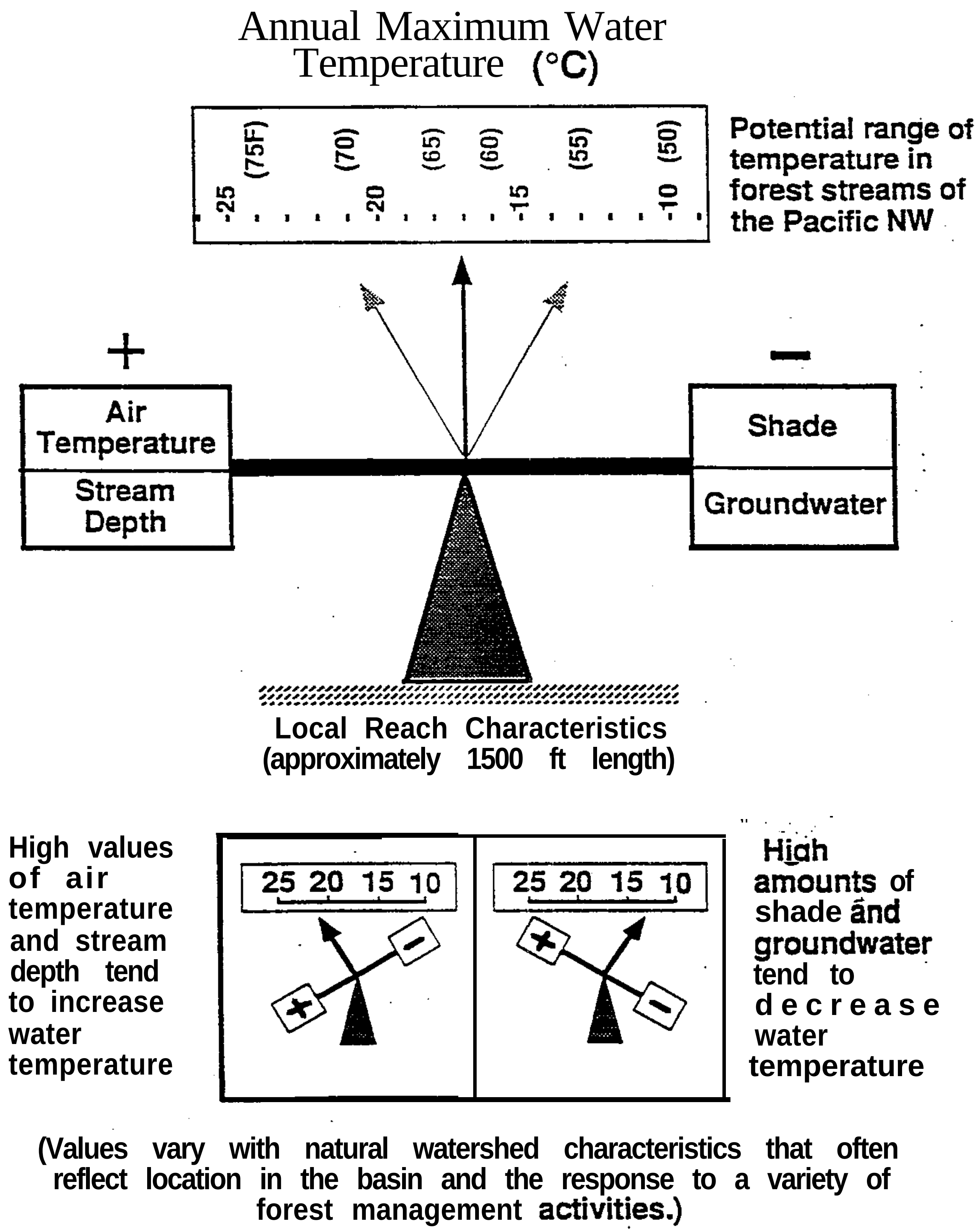



Fig. 2.1 Maximum equilibrium concept

**Maximum Equilibrium Temperature:** The maximum equilibrium temperature of each stream reach is independent of observed air temperature and is related primarily to the site conditions (Figure 2.1). Each reach's equilibrium temperature is determined by its unique combination of physical characteristics that influence stream heating. These include stream channel features (depth, width, velocity, substrate composition), riparian shading, and geographic location (latitude, elevation).

The numerous site characteristics contributing to the determination of stream temperature may vary inter-dependently, independently, or inversely. The maximum equilibrium temperature should relate to site characteristics in identifiable, albeit complicated, ways. Nevertheless, common relationships between maximum equilibrium water temperature and site conditions exist. Changes in the local environmental conditions are likely to cause a change in the equilibrium temperature to a new value. Common responses to changes in site conditions with land use can be identified.

The annual maximum temperature is a good measure of the maximum equilibrium temperature. This temperature may not be observed frequently, depending on the climatic conditions, but it is indicative of the balance of site characteristics. Generally, the maximum equilibrium temperature in all streams and rivers will occur somewhere within the range between 48 and 77°F (9 - 25°C).

The T/F/W temperature study demonstrated several other principles of stream heating at both the stream reach and basin scales, The following information summarizes some of the findings reported in Sullivan and others (1990).

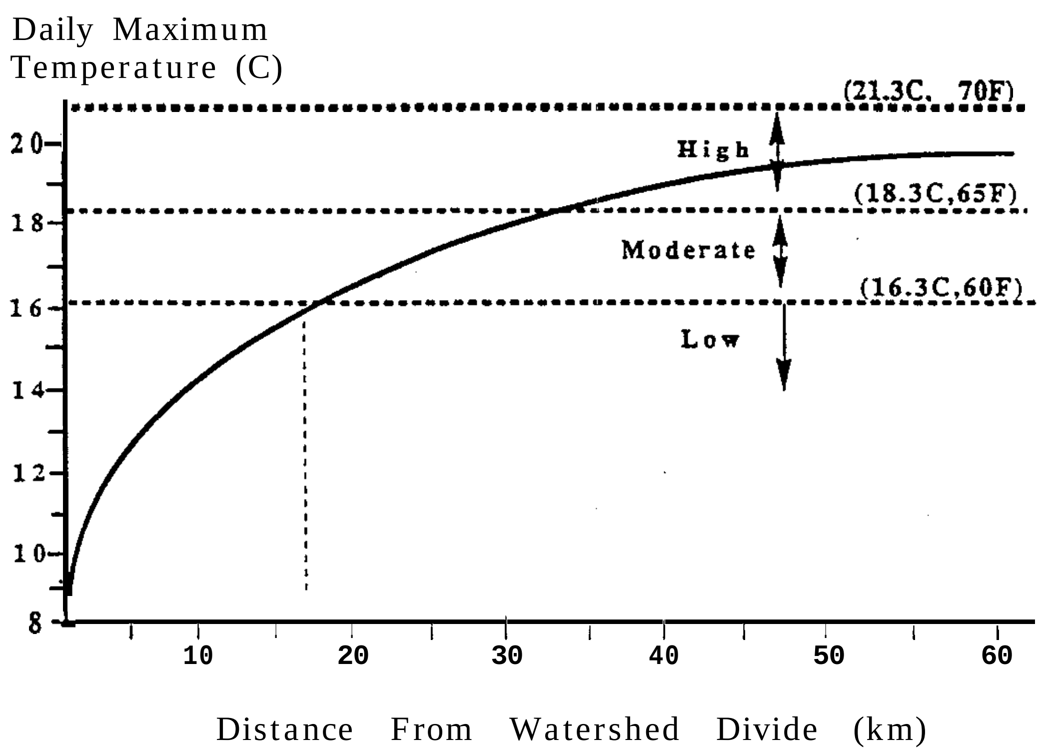
**Stream Reach Temperature:** Stream temperature and site characteristics were evaluated to identify what features could be used to recognize streams exceeding the Washington water quality temperature criteria. A number of environmental factors were well correlated with stream temperature. Several good empirical relationships between stream characteristics and water temperature were developed based on five of the most important environmental variables including stream shading, mean air temperature, elevation, stream discharge, and bankfull width. Other variables more directly influential in the physical processes of stream heating were also identified, but of the well-correlated variables those that are easiest to measure were selected. Typically, a combination of local environmental factors had an important influence on water temperature, but no one factor alone was a good predictor of stream temperature.

**Basin Temperature:** All basins showed general warming of water temperature in the downstream direction, which is consistent with theoretical relationships. Past observations have described a nearly universal tendency for stream temperature to increase logarithmically with distance (Hynes 1970, Theurer and others 1984). Downstream warming occurs because: (1) increasing stream width reduces the effectiveness of riparian vegetation to shade the stream surface; (2)the proportion of cooler groundwater inflow relative to the flow in the channel decreases; (3) stream depth generally increases in the downstream direction, and; (4) air temperature increases at lower elevations.

Baseline Maximum Temperature: The temperatures within reaches flowing through mature forests were evaluated to estimate the expected baseline maximum equilibrium temperatures within watersheds fully forested with mature conifers. Measured values of maximum daily temperature during the warmest summer period of approximately 20 forested stream reaches of all sizes were used to draw the relationship between maximum water temperature and increasing stream size (indexed as distance downstream from the watershed divide) shown in Figure 2.2. This graph depicts the best estimate of baseline maximum daily temperature within fully forested watersheds available at present.

Small streams relatively close to the watershed divide are very cool 50 - 56°F (10 - 14°C) with the smallest streams near groundwater temperature. (This represents the minimum possible summer temperature.) Stream reaches within forested riparian zones located approximately 12 miles (20 km) downstream from the watershed divide are likely exceed 62°F (16.3°C). Those sites greater than 30-40 miles (50-60 km) from divide are likely to exceed 65°F (18.3°C) during the warmest periods of the year, regardless of forest management activities upstream. Local deviations in this general trend can occur such as where cooler or warmer tributaries join the system, or at the interface between rivers and oceans where air temperatures may be cooler than similar elevations located inland. Therefore, the baseline maximum temperature in figure 2.2 should be considered a rule-of-thumb and can vary with local conditions. Regional validation of this relationship would be useful.

*Figure 2.2 Estimated baseline daily maximum temperature during the warmest summer days under a mature forest canopy as a function of distance downstream from watershed divide.*



## 2.2 Forest Management Effects On Stream Temperature

Considerable research has been conducted in forested watersheds on temperature changes from shade removal along channels during timber harvest. Brown and Krygier (1970) demonstrated that reduced stream shading results in generally higher stream temperatures and increases in diurnal water temperature fluctuation in Oregon forest streams. Daily maximum temperatures in very small streams tend to have the largest response to forest canopy removal. Studies conducted in various locations in the United States have also shown potentially large increases in daily maximum temperatures with removal of forest vegetation. Beschta and others (1987) provide a complete review of harvest effects in forest stream environments from previously published studies. One of the largest increases in daily maximum temperature (16°C, maximum l-day temperature) was documented by Brown (1969) in a very small stream in coastal Oregon. More typically, increases of 3-7°C in daily maximum temperature can be expected with removal of significant amounts of shade from the streamside zone.

Temperatures of all the mainstem rivers studied appeared to be somewhat warmer within distances of 50 km from the watershed divide than would probably be expected for similar streams in old growth conifer forests. Effects of past riparian management appear to have resulted in increases of 5 - 9°F (3 - 5°C), depending on stream size.

Sullivan and others (1990) found that shading from riparian vegetation has an important influence on stream temperature. In addition the extent of the cooling effect of shading varied with site elevation. The importance of shade and elevation on water temperature are so great that with only these two variables stream temperature can be predicted relative to the water quality criteria with 89% accuracy.

## 2.3 Forest Practices and Water Quality Standards

**Water Quality Temperature Standards:** The water quality standards for surface waters of the state of Washington (Chapter 173-201-045 **WAC),** administered by the Department of Ecology, are linked to the Forest Practice Rules and Regulations through a provision for joint promulgation (Chapter 173-202 WAC). These standards and the water-related forest practice rules and regulations are designed to meet state requirements for non-point source pollution control under the federal Clean Water Act (Public Law 100-4) administered by the U.S. Environmental Protection Agency.

The water quality standards establish criteria based on three threshold temperatures for streams of different classes. For class AA streams (generally applicable to forest streams), the maximum water temperature shall not exceed 61°F (16.3°C) or the temperature increase from activities shall not exceed 5°F (2.8°C). For class A streams (generally applicable to larger rivers in forest zones and elsewhere), the maximum water temperature shall not exceed 65°F (18.3°C) or increase more than 5°F (2.8°C). For class B streams (generally larger rivers affected by industrial or agricultural activities and not typically found in forest land use zones), the maximum water temperature shall not exceed 21.3°C or increase by 5°F (28°C). Water quality classification of rivers in Washington is listed in WAC 173-201-080.

To protect fish habitat and other beneficial uses, the forest practice regulations (1988) stipulate that the average of maximum daily water temperature for seven or more sequential days should not exceed 60°F (156°C). The water quality standard described above is similar to but slightly more conservative than the forest practice regulation standard. It is expected that the Department of Ecology will recommend adoption of the water quality standard for forest practices and all results presented in this report are stated relative to it.

***Table 2.1 Temperature Criteria for Water Quality Standards***

| STREAM CLASS | CRITERIA | TEMPERATURE CATEGORY' |
|---|---|---|
| CLASS *AA* | Maximum less than 61.3" (16.3°C) | Low |
| CLASS A | Maximum greater than 61.3°F (16.3°C) and less than 64.9°F (18.3°C) | Moderate |
| ***CLASS B*** | Maximum greater than 64.9°F (18.3°C) | High |

*[1]The water quality standards do not include temperature categories.. Category is stated in this table as a convenience for making comparisons as discussed in this report.*

**Forest Practices Regulations:** Riparian zone management regulations (jointly promulgated by the Forest Practice Board and the Dept. of Ecology and administered by the Departments of Natural Resources and Ecology)_ are designed to meet the water quality criteria in the State water quality standards. Washington forest practice regulations specify shading requirements to protect stream temperature from adverse increases during the summer months.

Types 1-3 Waters (Fish-bearing streams). Within riparian zones along types l-3 streams, the operator must leave all non-merchantable material providing shade to the stream, and whatever merchantable material is required to maintain 50% of the *existing* shade. If the maximum daily water temperature exceeds the temperature criteria described above (termed "temperature sensitive"), then the operator must leave 75% of the existing shade. (See

Washington Forest Practices Rules and Regulations 1988; WAC 222-30-040).

Washington forest practice regulations specify that the temperature sensitivity of stream types 1, 2 and 3 shall be based on field data or records, or from a verified temperature model or method that demonstrate significant adverse water temperature impacts following the proposed timber harvest and shade removal. A stream must be designated temperature sensitive prior to or at the time of the forest practice application.

Tvpe 4 Waters (Small. eenerallv non-fish bearing streams). The smallest streams (type 4) do not ordinarily require leave strips of riparian vegetation. Temperature concerns along Type 4 waters can be addressed through the priority issues process if instream resources within the Type 4 stream are expected to be adversely impacted by warmer temperatures.

It is unclear whether these less shaded streams ***significant&*** affect the temperature of the fish-bearing streams they flow into. Because timber harvest patterns create a mosaic of vegetation conditions within watersheds, and because heated water can move downstream with flow, concerns remain that inadequate temperature protection measures in upstream waters may have adverse downstream impacts. Preliminary results of investigations into this question indicate that downstream temperature affects from Type 4 streams are limited lower in elevation. Furthermore the downstream affect appears to be only on the order of 150 m or less (Caldwell and others, 1991).

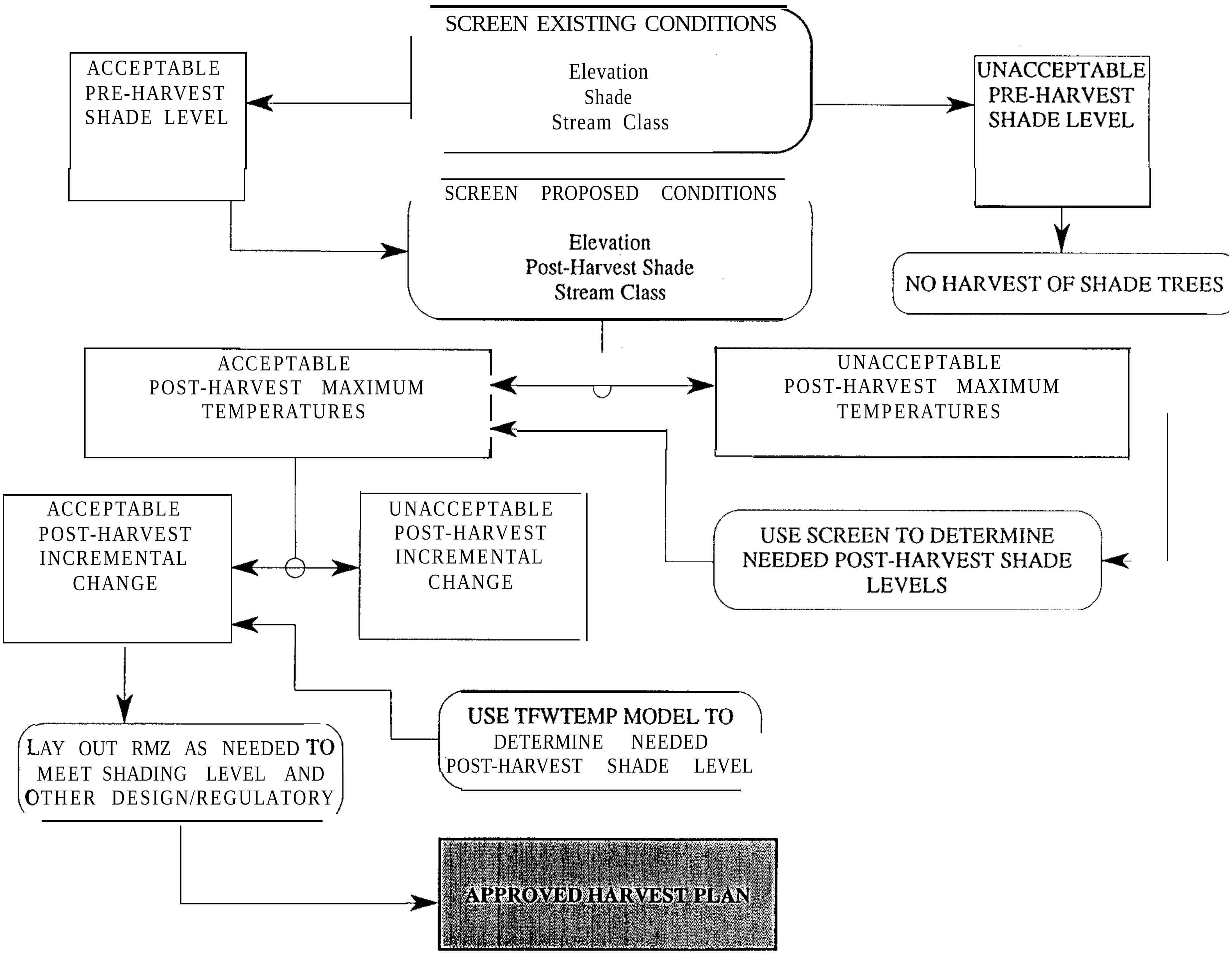
The cumulative length of small but abundant Type 4 waters relative to larger streams makes this question especially important.

## 2.4 An Evaluation of the Effectiveness of Current Regulations In Meeting WQ Standards

Understanding the effectiveness of riparian management regulations is an important consideration in developing a T/F/W temperature method. Determining how to identify locations not adequately protected by forest practice rules requires knowing where the rules are effective.

When this study was initiated in the summer of 1988, there were limited numbers of sites with riparian zones designed according to the 1988 T/F/W revised regulations. As a result, the study did not attempt to directly field test the effectiveness of the regulations in protecting water temperature. Instead, because the selected model proved to be so reliable at predicting temperature under all riparian conditions, the TWG thought it constructive to use the model to simulate the probable effect of the riparian management regulations developed in the T/F/W Agreement. In addition, field data from the 1988 TWG study including measured stream temperature were used to assess the effects of current regulations in much the same way as the prediction models were used. Both methods were used to evaluate riparian management zone rules for temperature protection. Although not a substitute for direct field-testing, this modeling exercise also provides an early indication of whether the riparian rules provide adequate temperature protection.

# Figure 3.1 Temperature Method Flow Chart



## 2.5 Recommended Shading to Meet Water Quality Standards.

Shading specified by the regulations was found to be generally inadequate for protecting temperature of types 1-3 waters. Based on study results, *total* stream shading of 50-75% after cutting is needed to maintain water temperature in most streams within water quality standards (rather than the 50-75% of the *existing* shade as specified in current forest practices rules). However, because the importance of shade varies with elevation, a shading guideline based on elevation of the site is recommended.

Surveys of riparian buffer zones left under the T/F/W rules indicate that forest managers are tending to leave more shade in riparian zones than required in the current reguiations and that shading generally meets the recommendations of this study. As expected, riparian zones along large streams (type 1) tend to have less shading, especially on the East side of the state, although sample sizes were small.

## 2.6 Temperature Models

Sullivan and others (1990) evaluated both analytical models based on physics of stream heating and empirical models based on common patterns of temperature in relation to site characteristics. The models' utility for T/F/W forest managers was included in the evaluation.

Four analytical reach temperature prediction models (Brown's Model, TEMP-86, U.S. Fish & Wildlife Service SSTEMP, and TEMPEST) were rigorously evaluated for prediction accuracy and practicality of use. A sensitivity analysis was performed to determine each model's sensitivity to key input parameters of importance to stream temperature (for example, shading, air temperature, solar radiation, and stream depth). Several of the models were found to predict water temperature with reasonable reliability, even when input data was estimated, although models varied in predictive capability and practicality. One reach model was selected that satisfied both prediction accuracy and practicality criteria developed with T/F/W field managers in mind.

Three basin, or multi-site, analytical models were tested (EPA QUAL2E, USF&WS SNTEMP, and MODELY) on sites grouped in three river basins. The basin models were more cumbersome to use than reach models. Data requirements were intense to the extent that general forest managers could not be expected to routinely commit the time or resources required to run a basin model on a widespread basis.The models were also not very reliable temperature predictors when used in a manner that could be expected in routine T/F/W use. None of the basin models performed well enough, were sufficiently practical and reliable, or had appropriate gaming capabilities to recommend their use in planning forest activities.

Stream data were explored to determine what site characteristics are associated with those streams most likely to have low, moderate or high temperature. It was generally observed that unshaded streams tended to have moderate to high temperature, while fully shaded small to medium-size streams tended to have low temperature. These patterns were more fully explored in developing a temperature screening method.

Although many characteristics were shown to correlate with stream temperature, two factors were of such overwhelming importance that they could be used to reliably predict temperature categories. These two factors are shading and elevation (the latter probably indicates air temperature regime). A simple graphic model (the temperature “screen”) based on these characteristics correctly identified the temperature category according to water quality criteria for 89% of the sites.

SECTION ID USING THE **TEMPERATURE METHOD**

## 3.1 General Information

The method described below is designed to assist managers in determining the amount of shade needed to protect Types 1-3 streams from exceeding the Water Quality (WQ) temperature criteria. The evaluation consists of seven steps. It is important to complete all of the steps requested. Figure 3.1 shows a simplified flow chart of the decision making process.

This method should be used when designing or evaluating timber harvest plans which include the removal of any trees shading types 1 - 3 waters regardless of the location of these shade trees relative to the RMZ. Applying the method to sites above 3600 feet MSL is not necessary as these stream reaches will almost always meet the water quality criteria. Conversely, stream temperatures in very large, wide streams may not be affected by alterations to riparian trees for several reasons. First, as discussed in section 2.1, temperature in larger streams is less responsive to environmental changes. Second, the ability of trees to provide shade to the stream is partially a function of the stream width. The canopy opens as a stream becomes wider.

The method for determining compliance with water quality temperature criteria depends upon two basic tools; a graphical temperature screen, and a computer model for predicting temperatures. A brief background on each of these tools is presented below. Those familiar with the screen and model may wish to skip to section 3.4 for specific directions on determining RMZ shade levels necessary to meet the water quality temperature criteria.

## 3.2 Understanding the Screen

The temperature screen was developed by analyzing temperature and stream characteristics for 92 Washington streams. A full discussion of the screen development is provided in Sullivan and others (1990). The screen boundaries between acceptable and unacceptable temperatures are based on temperatures specified in the Washington Water Quality Standards (WAC-173-201). The maximum temperatures for class AA and class A streams are 61.3°F (16.3°C) and 64.9 (18.3°), respectively. The maximum temperature will not likely be exceeded if the stream reach is managed for an acceptable percentage of shade at the specified elevation.

Information needs to use the temperature screen include stream classification,elevation, pre-harvest shade, and post-harvest shade. Stream classification is identified in Appendix C. USGS topographic maps or DNR water type maps provide elevation information. Measure the elevation at the midpoint of the RMZ. If the difference in elevations between the two ends of the RMZ is greater than 600 feet, then it is suggested to divide the RMZ into two or more sections of equal length and evaluate stream temperature separately for each section. Methods to estimate shade are provided in sections V and VI.

Each RMZ within the harvest unit should be treated separately. If the RMZ includes more than one stream type or stream class, these should also be evaluated separately.

## 3.3 Understanding the TFWTEMP Model

TFWTEMP is a temperature model developed specifically for T/F/W users. It was developed from the TEMPEST model (Adams and Sullivan 1990) which was tested in the study presented in Sullivan and others (1990). Unlike the TEMPEST model for which climate data must be provided, the TFWTEMP model internally calculates several climatic and stream characteristics dependent upon the information the user provides. Correctly interpreting the model results requires some level of understanding as to how the model works. A description of the information values the user must provide as well as those estimated internally by the model is provided in sections 3.5 and 3.6.

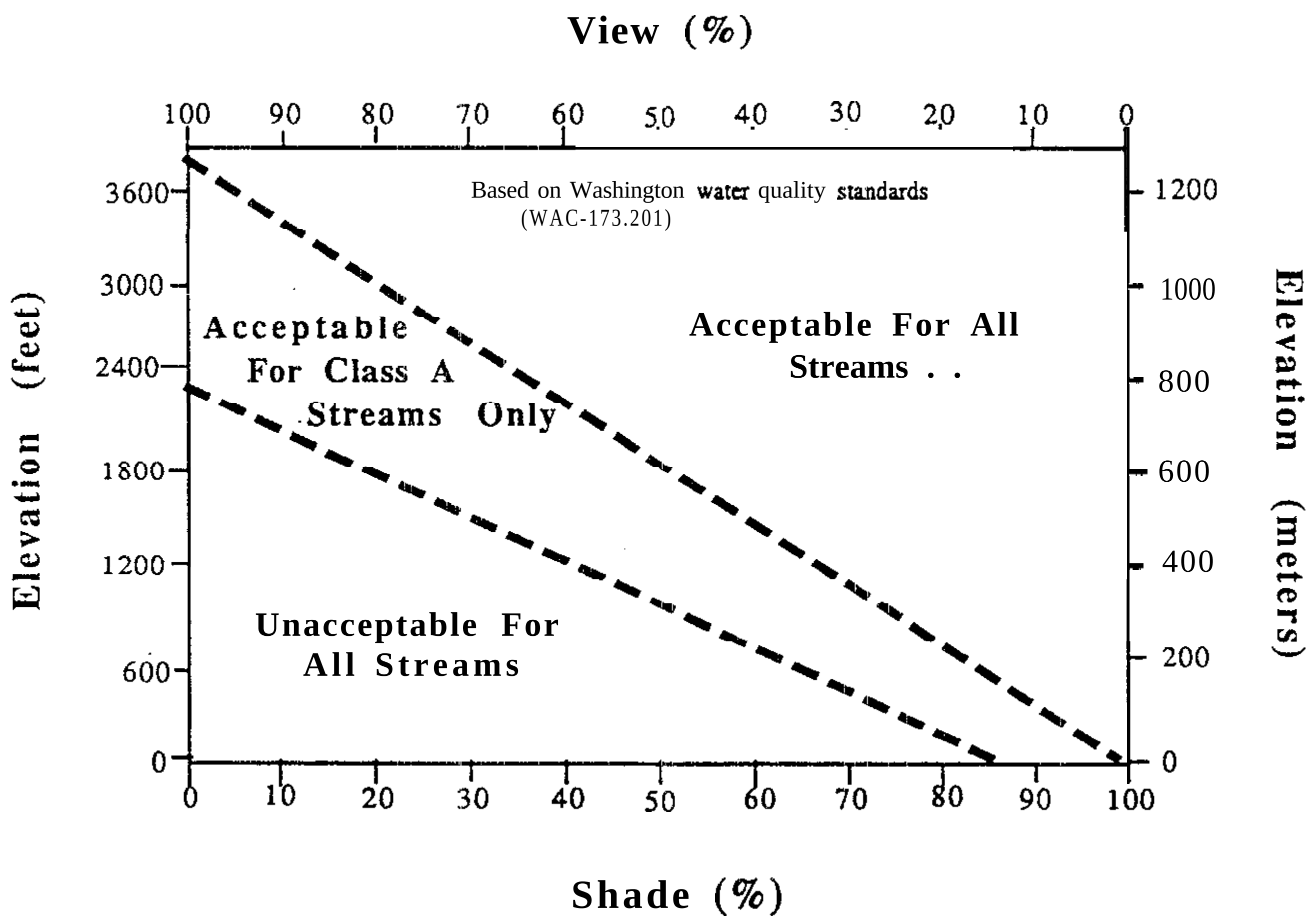



**Figure 3.2 Temperature categories** for type 1-3 streams based on Washington mater quality standards. Temperature categories are divided by broad dashed line.

### 3.4 Evaluation Steps

Complete the following steps for each stream flowing through a proposed harvest area. Be sure to complete all of the steps requested.

1. Gather the following information about the site. Determine the stream class - Class A or AA. See Appendix C. Note that the water quality stream class is different than the forest practices stream type. The site elevation (within forty feet) must also be known. Select an, elevation at the midpoint of the stream reach within the proposed harvest area. If the difference in elevations between the two ends of the RMZ is greater than 600 feet, then it is suggested to divide the RMZ into two or more sections of equal length and evaluate stream temperature separately for each section. An estimate of pre-harvest and post- harvest shade percentage is necessary. Sections V and VI of this manual discuss how to measure the percent shade before and after harvest.

2. Plot the pre-harvest site conditions of elevation and shade on the shade requirement chart (fig. 3.2).

3. Test Pre-harvest stream temperature conditions.

   - If the chart indicates the site conditions are acceptable, some shade removal is possible. If the plotted point falls directly on the dividing line between acceptable and unacceptable, conditions should be considered unacceptable. However, continue with the remaining steps to verily conditions.

   - If the chart indicates site conditions are unacceptable, there is not adequate shade in the pre-harvest condition to meet the water quality standard. Therefore, no shade removal is allowed. All trees within the RMZ must be left. Trees outside of the RMZ that are effectively shading the stream must also be left. If no removal of shade trees is planned, completion of steps 4 - 6 is not necessary.

   Occasionally, the stream classification is not consistent with existing ambient temperatures. The water quality stream classification system is based on other water quality parameters in addition to temperature. Therefore, certain sites may be exempt from the class AA temperature criteria. See section 3.8 for guidelines for evaluating stream classifications.

4. Determine if the proposed activity meets the maximum stream temperature criteria.

   Plot the expected post-harvest conditions on the shade requirement chart (fig. 3.2).

   - If the chart indicates post-harvest shading is acceptable, the RMZ meets the maximum temperature criteria. Note the acceptable post-harvest percent shade and go on to the incremental test (step 5). If the plotted point falls directly on the dividing line between acceptable and unacceptable, conditions should be considered unacceptable. However, continue with remaining steps to verify conditions.

- If the chart indicates post-harvest shading is unacceptable, the proposed harvest calls for too much shade removal. If implemented the plan would likely result in an exceedance of the maximum temperature criteria. Do not proceed with the incremental test (step 5 and 6). The harvest plan needs revision before repeating this step and continuing the test.

5. Determine if the incremental temperature increase criteria is met.

Where needed, the 'TFWTEMP Model is used to determine the change in temperature that is likely to occur when shade cover is removed from riparian areas. The model allows one to "game" with the riparian conditions until the appropriate shade requirements are met.

In many cases, it is not necessary to use the model. Only when the conditions are likely to cause an increase in temperature greater than 5°F (2.8°C) does the model need to be run. The information below is designed to help determine whether the model, TFWIEMP, should be run.

Under the following conditions the computer model, TFWIEMP, needs to be run. In these situations the incremental temperature increase with shade removal may exceed the thermal criteria..

(1) Values for existing pre-harvest shade are less than the values listed in table 3.1;

-AND-

(2) The planned or possible harvest will reduce shade by more than 25%.

- If both (1) and (2) are true then proceed to step 6.

- If either (1) or (2) is not true then the criteria for the incremental increase in temperature due to the proposed harvest is met. The temperature increase will likely be less than 5°F (2.8°C). Proceed to step 7.

| Table 3.1 Incremental Temperature Increase Criteria Test | | |
|---|---|---|
| ELEVATION (feet) | PERCENT SHADE BEFORE HARVEST | |
| | CLASS A STREAMS | CLASS AA STREAMS |
| 0-655 | 85 | Incremental increase <5.0°F. |
| 656-1310 | 75 | 90 |
| 1311-1970 | 55 | 75 |
| 1971-2625 | 45 | 65 |
| > 2625 | Incremental increase <5.0°F. | |

*If the existing shade before harvest is less than indicated in this table and the proposed harvest will reduce the shade by more than 25%, use of the TFWTEMP model is required The TFWTEMP model is not necessary for class AA streams below 656 feet and all streams above 2525 feet since shade reduction at these sites is not likely to result in the exceedance of the incremental temperature criteria*

6. Run the TFWTEMP model. Detailed operating instructions are provided in Section IV.

   Run the model for pre-harvest conditions. Note the predicted maximum temperature and confirm that the maximum temperature is acceptable.

   Run the model for proposed post-harvest conditions. Note the maximum temperature and subtract it from the maximum temperature for pre-harvest conditions. If the difference is greater than 5.0°F (28°C) the incremental temperature increase criteria will be exceeded by the proposed harvest. Run the model again with a greater value for remaining shade after harvest. Continue "gaming" with the model until the incremental increase in temperature with harvest does not exceed 5.0°F (2.8°C) **AND** the model indicates the maximum temperature for post-harvest conditions is acceptable. Once a shade percentage that meets both the maximum and the incremental increase criteria has been identified proceed to step 7.

7. If step 5 required the use of the TFWTEMP computer model, subtract the post-harvest shade value identified in step 6 from the pre-harvest shade value used in the TFWTEMP model. The difference is the maximum amount of shade that can be removed and prevent exceedance of the water quality criteria.

   If use of the computer model, TFWTEMP, was not required, subtract the post harvest percent shade identified as acceptable in step 4 from the pre-harvest shade percentage. The difference is the maximum amount of shade that can be removed and prevent exceedance of the water quality criteria.

Examples: The following are examples showing how the above described method is applied to forest practice applications.

EXAMPLE 1. In this example the elevation is 2400 ft. and there is 90% shade along the class AA stream before harvest.

According to figure 3.2 the maximum temperature before harvest is acceptable.

The estimated amount of shade after harvest with a standard RMZ design is 50%. Fig. 3.2 indicates that the maximum temperature criteria will be met.

Table 3.1 is next consulted. The incremental criteria will also be met.

EXAMPLE 2. In this example the proposed harvest unit is at 1300 ft. with proposed harvest along a class A stream with 70% shade before harvest.

The estimated amount of shade after harvest if a standard RMZ is used will be 50%. Fig. 3.2 indicates the maximum criteria is acceptable for class A streams.

Table 3.1 suggests that the incremental **criteria** may not be **met** and recommends verification with the TFWTEMP model. Given that the site is in Eastern Washington at a distance of 10 miles from the divide the maximum stream temperature before harvest is 55.4" before harvest whereas TFWTEMP predicts a temperature of 60.8°F after harvest. The incremental criteria is not **met** (ie. >5°F increase).

Run the TFWTEMP model again with additional shade left after harvest. Design the RMZ according to the shade level required to meet both the maximum and incremental criteria as well as other design requirements.

EXAMPLE 3. The third example is a site at 900 ft. elevation with 65% shade before harvest on a class AA stream.

The maximum criteria is not met with existing conditions. No harvest of any shade trees is allowed. Review section 3.8 of this manual if you have any questions regarding the stream classification.

## 3.5 TFWTEMP Model: Information Supplied bv the User

The TFWTEMP model requires several input values in addition to the information necessary to use the temperature screen.

**Temperature Region:** Washington State has been divided into three temperature regions based on the results of the 1988-90 T/F/W Temperature Study (Sullivan and others 1990) These are: Coastal, Western and Eastern. Figure 3.3 shows the boundaries for each region. The model will use this information along with elevation and distance from divide to select the appropriate climate data for modelling. Users modeling sites in the Washington Cascades east of the Cascade Crest will need to decide if their particular site is more correctly defined as East or West.

**Distance from Watershed Divide:** Distance from watershed divide is measured from a USGS topographic map, and is defined as the distance along the stream from the site to the most distant upstream point m the basin on the watershed divide. The actual stream length (not the direct linear distance) should be measured on the map. Use topographic contours to approximate stream channel configuration if the stream is not indicated on the map.

DNR water type maps or, 7.5 or 15 minute USGS maps may be used to measure distance from divide. The water type maps are more exact but may prove cumbersome for sites a long distance from the divide. Figure 3.4 provides a graphic explanation.

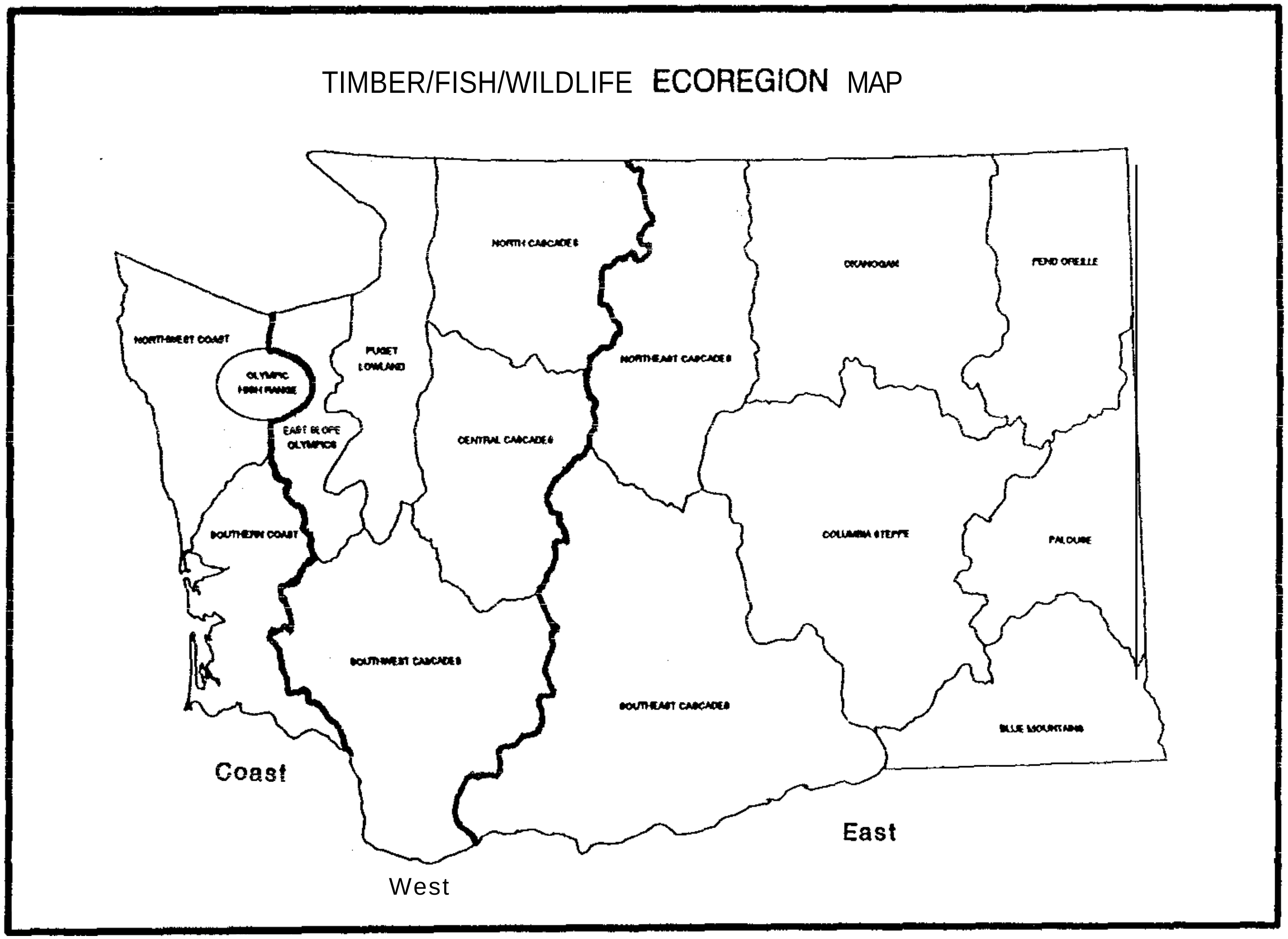
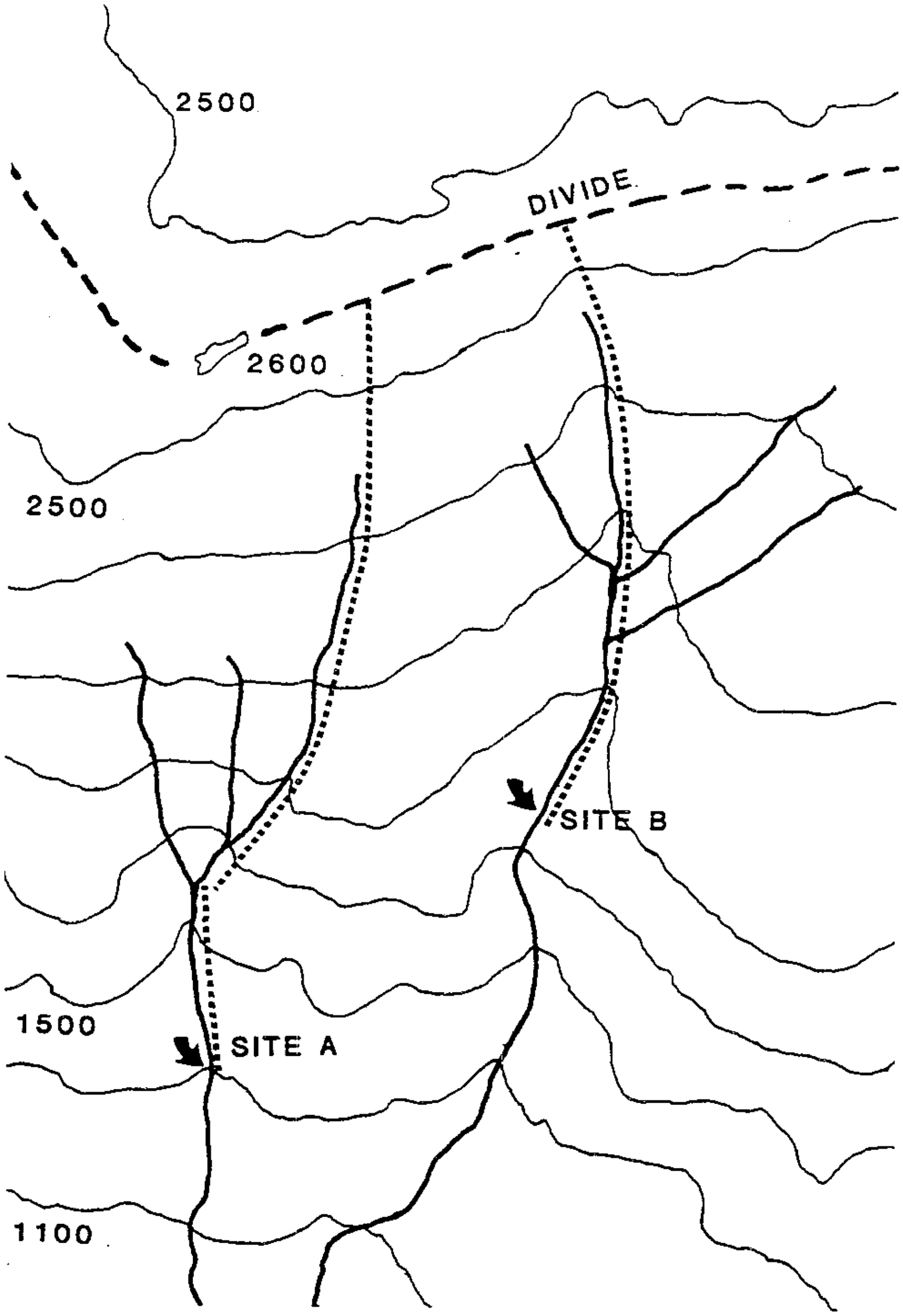



Figure 3.3 Regional Designations for Stream Temperature Method




**Scale: 1 inch : 1 mile**

Use a 7' or 15' USGS topographic map, or a Water Type map. Pinpoint the site(s). Determine the divide, by freehand-drawing a line between the next-to-highest contour lines (2500 ft. in this example), making sure you intersect with the highest contour line as well (2600 ft.). Using a ruler or a map wheel, measure from the site up to the hand-drawn divide line, moving up the stream channel. (Use the contour lines to approximate the channel if the channel is not on the map.) TFWTEMP requires the distance-from-divide value in miles or kilometers.

In this example, the distance from divide for Site A is 4.5 mi., and 3.4 mi. for Site B.

Figure 3.4 Distance from Divide Determination

## 3.6 TFWTEMP Model: Specified Values

The TFWTEMP model uses default values for other parameters needed to run the model. These default values are derived from regional relationships for each parameter, based on data collected and evaluated during the 1988-90 T/F/W Temperature Study (Sullivan and others 1990). It is expected that these default relationships will be improved as more information becomes available.

**Groundwater Inflow Rate and Groundwater Temperature:** A standard groundwater inflow rate of 0.253 cfs/mile is used in the model. This value was derived from data gathered for the study presented in Sullivan and others 1990. The model calculates the groundwater temperature dependent upon the elevation and temperature region selected by the user. Values are reported in the model output and should be compared to local knowledge.

**Stream Depth:** Stream depth affects the diurnal range in predicted stream temperature. The model calculates the stream depth dependent upon the distance from watershed divide value provided by the user. The derivation of this relationship is reported in (Sullivan and others 1990). The estimated value provided by the model is an average depth for the stream; inclusive of both pools and riffles.

**Air Temperature Profiles:** The model automatically selects one of seven air temperature profiles, according to the temperature region and elevation provided by the user. The model uses NOAA regional meteorological data and adjusts it for the site elevation. The air temperatures are hourly profiles for normal conditions during the period July 15 through August 15. Later versions of the model may provide the user the opportunity to provide hourly air temperatures as an input value. Because air temperature and relative humidity are closely related, it is then necessary for the model to calculate the relative humidity.

**Other Climate Information:** In addition to air temperature, the model also automatically selects the appropriate relative humidity, solar insolation, and average cloud cover corresponding to the air temperature profile for the period July 15 through August 15. These values are also based on NOAA regional long term records.

## 3.7 When is Field Work Necessary?

**A. The Testing Period:** During the testing period, it will be necessary for users of this method to measure existing shading and to estimate post-harvest shading in the field. While two years of data have been collected on 'T/F/W" Riparian zone characteristics, there is not yet enough information to allow presentation of typical existing or post-harvest canopy closure characteristics, using a database indexed to ecoregion, elevation, forest types and stream size. In order to make the testing period most useful, we recommend that co-operators and testers measure shading characteristics using a densiometer or other methods described in section V. For a further discussion of the currently available information regarding riparian shading, see section 3.11.

**B. Disagreements and Unique Site Concerns:** When the model and temperature screen disagree, or when the user is evaluating a site known to be far from local norms, additional field investigation is warranted. Important considerations to resolve include the appropriateness of the air temperature profile and stream depth chosen by the TFWTEMP model. Section 3.6 discusses how the model estimates this information. See (Sullivan and others, 1990) for technical background on the influence of these site characteristics on stream temperature.

**C. Greater than 50% Canopy Closure Required:** A preliminary analysis of sites harvested under the T/F/W standard RMZ rules indicates that, in general, 50% to 75% canopy closure remains after harvest. For sites where the temperature screen (fig. 3.2) indicates greater than 50% canopy closure is required to meet the water quality criteria, then on-site design of the RMZ to select those trees to be left for providing shade is required.

## 3.8 Review of the Stream Classification System

The stream classification system described in Appendix C is based on water quality concerns for Washington streams. In addition to temperature, the stream classification system recognizes other water quality criteria. This creates a situation where, occasionally, the division between class A and class AA streams may appear inappropriate when evaluated solely for the water temperature component. This may result in specification of water temperature criteria that are lower than naturally occurring temperatures under pristine conditions.

As a general rule of thumb, stream reaches that are more than 12 miles (20 kilometers) distance from the divide are likely to exceed the class AA maximum temperature criteria even under a mature forest canopy. Local deviations in this general trend can occur such as where cooler or warmer tributaries influence the system, or at the interface between rivers and oceans where air temperatures may be cooler than similar elevations located inland. This rule of thumb has not yet been fully tested on a regional basis.

Determine the distance from divide for a stream reach according to instructions in section 3.5. If the site is greater than 12 miles (20 kilometers) distance from divide and is a class AA stream, use your local knowledge to compare temperatures at this site to those of other similar streams in the region. The Department of Ecology will make decisions regarding exceptions in the water quality temperature criteria.

The following modelling exercise may be helpful in situations where you believe the stream classification for a site may inappropriately identify the maximum allowable temperature. Run the TFWTEMP model for a range of percent shade values. Determine what percent of shade is necessary to predict a maximum temperature of approximately 61.3°F and 64.9°F, the maximum temperature for class AA and A streams respectively. Consider if this percentage of shade is possible for the size of the stream were a mature riparian forest canopy present. If you determine that it would be difficult to meet the class AA criteria but possible to meet the class A criteria, an TFW ID team meeting may be warranted. However, unless the Department of Ecology provides an exception or other specific guidelines, you must use the stream classification identified in appendix C for evaluating shading requirements.

### 3.9 Temperature Screen Accuracy

The temperature screen correctly sorted 42 sites across the state, whether or not they exceeded the maximum temperature criteria, 89% of the time (See Ch.7, Sullivan and others 1990). Individual decisions can always be made regarding resources at risk in an individual stream. While the TFWTEMP model allows a comparison of results, the model is not necessarily more accurate than the screen at correctly identifying exceedance of the maximum temperature criteria. If greater accuracy is desired, the TEMPEST model is recommended.

### 3.10 Limits On Model Use

Because the TFWTEMP model relies on regional climate profiles for normal conditions, the predicted stream temperatures may differ from measured stream temperatures. Variations in climate occur within regions and conditions vary from year to year. While comparing actual water temperature data to TFWTEMP predicted temperatures offers an interesting comparison, the use of the TEMPEST model (Adams and Sullivan, 1990) is recommended for those who desire precise site and time specific predictive capabilities. However, the TFWTEMP model, for most situations, is very adequate for determining riparian management prescriptions and is easier to supply with input data.

The internal calculations in TFWTEMP for climatic and some channel characteristics are not appropriate for use outside Washington state. Users in other regions are cautioned against use of the TFWTEMP model as currently configured and are referred to the TEMPEST model which requests site specific data rather than regionalized estimates.

### 3.11 Information Gaps: Canopy Closure

At this time, the largest information gap in using this method is the relatively small amount of information that is available regarding typical pre-harvest, mature forest shading conditions over a range of stream sizes, regions and forest types; as well as the relatively small database that describes shading characteristics of RMZs left after the 1988 TFW Agreement.

Neither problem is insolvable, although both information sets impose some limitations on the model testing period. Until adequate databases can be developed, field measurements of pre-harvest shading, and visually estimating post-harvest shading is necessary. Field measurements during the testing period will serve two purposes. First, the additional data will enlarge the knowledge of pre-harvest shading conditions. Second, the test of the method will avoid possible bias from inappropriate use of "average" shading values for each stream type.

Coordinated efforts to collect more information open shading values, forest types, seral stage, stream widths, and distance from the watershed divide in mature forest stands are needed. These measurements could readily be accommodated within other T/F/W monitoring activities. With additional data collection, a database indexed to temperature region, elevation, forest types and stream size can be developed to aid pre-harvest canopy closure value specification during future routine use of this method.

At this time, how to correctly specify post-harvest shading levels is also under discussion. Information from two years of data collection, by Washington Dept. of Wildlife, on RMZs across the state is summarized in Table 3.2. While average values can indeed be determined, at least for Western Washington sites, the range of observed values around the mean is large.

Use of the regression equation (table 3.2) to estimate pre-harvest shading levels, or the average shading values from the WDW Riparian Database is not a recommended option at this time. However, table 3.2 summarizes the available information on riparian shading for a comparison to site specific measurements.

For future routine use of this method, a small amount of further field investigation should allow the construction of estimates of pre- and post-harvest shading. This would simplify the evaluation procedures and allow efforts to be concentrated on those streams of highest concern relative to potential stream temperature impacts.

**Table 3.2.** **Summary of Best Available Shading Information**

Mature Forest (baseline) Canopy Closure Values

Estimation Method:

View Factor (%) = 13.1 + 1.95 (Distance from Divide, Km)

(R-Squared = 0.66)

(Note: Canopy closure value ≈ percent shade = (l-view factor)

Source: Sullivan and others, 1990.

Post-Harvest Canopy Closure Values for TFW RMZ's

| Temperature Region | Water Type | Average Shade (%) | Range of Shade Values (%) | Number in Sample |
|---|---|---|---|---|
| East | 1 | 15 | -- | 1 |
| East | 2 | 41 | -- | 1 |
| East | 3 | 72 | 15-91 | 9 |
| west | 1 | 61 | 8-96 | 22 |
| West | 2 | 70 | 23-98 | 11 |
| west | 3 | 78 | 32-99 | 57 |

Source: A. Carlson, WDW, pers.comm. Data is from 1988 and 1989 riparian field surveys. Values for each stream are averages of 2-10 observations.

NOTE:

View Factor: 100% = open to sky, 0% means totally shaded

Canopy closure value is the inverse of View factor. 100% means totally shaded, 0% is open to sky.

## SECTION IV OPERATING THE TFWTEMP MODEL

### 4.1 General Instructions

This section of the manual provides a step by step approach to running the model. Programming has been done to make running the model easy. Directions are **written in** standard print. The commands you enter on the keyboard are printed in **bold. The** computer's response, which will appear on your screen, is printed *in italics.*

### 4.2 System Requirements

An IBM compatible computer with at least 512 K RAM is required. Your screen may be monochrome or color. You may run the model on either a dual floppy drive or a hard disk system. A printer of any specification is required to print results. The printer should be connected by a parallel communications port.

### 4.3 Installing the Model

If you are a first time user begin with step 1, otherwise you can simply copy the file(s) on the TFWTEMP disk to your hard drive or another floppy disk. If the model is already installed on your computer skip to section 4.4.

Steps 1 - 4 describe how to install TFWTEMP on your computer.

1. Turn on your computer, put the TFWTEMP disk in drive A, and log onto A drive by typing:
   A: then hit the ENTER key
   Start the installation by typing:
   **INSTALL** then hit the ENTER key

   The first question the installation program will ask you is whether you want the model copied to your bard disk or a floppy disk; answer by typing:
   **F** or **H**
   or choosing *H* as the default.

   If you chose to install the model to your hard drive then you will be asked to select the path to which the model will copied. The default path is *C:\TEMP.* At this point you can do one of three things:
   a) Choose the default by hitting the ENTER key.
   b) Type your own drive and path.
   c) Edit the drive and path.
   If you type something without moving the cursor, **the** string will be erased and you start over. So, if you just need to change the drive letter, first move the cursor to the right and then back to the left.

If you chose to install the model to another floppy disk then you will be asked to select the drive to which the model will be copied. The default is B:. Hit enter to except the default drive letter or type your own drive letter and hit enter.

The installation program will then copy the model to the appropriate drive and path.

You have copied the diskette. Put away the original. If you chose to install the model to a floppy then label the new diskette "TFWTEMP_date" and place this diskette in the A drive. Go to step 2.

2. Are you using a dual floppy drive system?

   If YES, go to step 3.
   If NO, go to step 4.

3. Operating TFWTEMP on a floppy system: With your computer on, the prompt showing A:\, and the TFWTEMP diskette in the A drive, type **tfwtemp.** The program will automatically start. Go to section 4.4.

4. Operating TFWTEMP on a hard disk: Log onto the drive to which the model was copied if it wasn't already by typing:
   **C:** then hit the ENTER key
   assuming that C drive is the drive you are using. Change to the TEMP directory or the directory you specified by typing:
   CD **C:\TEMP** then hit the ENTER key.
   Type **tfwtemp,** the program will start.

Continue with section 4.4 to run the model.

## 4.4 Running the model:

1. If you have not already done so, type tfwtemp and the model will begin.

   Following are screen - by - screen directions. Help screens are available while you are using the model. Simply press the F1 key on your keyboard.

   The model begins with the main menu. It is necessary to enter values for each of the items before generating a report. Use the up and down arrow keys to highlight each item. Once highlighted press return to provide an input value.

   The computer will prompt you if you enter an unacceptable character.

2. USER IDENTIFICATION. This can be a name, number, or initials.

The model will be listing the input values on the screen as you proceed.

3. SITE IDENTIFICATION OR FPA NUMBER. This will show up on the model's output.

4. STREAM CLASSIFICATION. Use Appendix C to determine the site's stream classification. Curser up or down to make your selection then hit return.

5. TEMPERATURE REGION.

Washington State has been divided into three temperature regions based on the results of the 1988-90 T/F/W Temperature Study. These are: Coastal, Western, and Eastern. Figure 3.3 shows the boundaries for each region. The model will use this information along with elevation and distance from divide to select the appropriate climate data for modelling.

Use the arrow keys to select a region and then hit the return key.

9. MEASUREMENT. The model has the option to use either metric or English units. You may select either. However, the units remain consistent throughout the model (i.e. specifying metric for input will yield temperature results in Centigrade.) A conversion chart is provided in Appendix B.

10. DISTANCE FROM DIVIDE. This screen asks you for a measurement, made on a map, of the distance from divide to your site. See section 3.5 for an explanation of how to measure this value.

11. ELEVATION. This should be the elevation at the midpoint of the RMZ being investigated. If the RMZ is very long (over 2000 ft.), or loses a significant amount of elevation across the unit, you should consider modelling the RMZ in smaller segments.

The model will only accept elevations of 1 - 5,000 feet (0.3 - 1524.4 m)

Type the elevation for the site followed by hitting the return key.

12. HARVEST TIME. Select before or after harvest dependent upon the conditions you are modelling. Harvest time will be listed on the model output, to identify predictions correctly.

13. SHADE PERCENT. This screen asks you for the shade percent, specified for both stream banks. If there is no difference between shade on either stream bank then

the same value can be used for both left and right. If timber harvest is to occur on only one side of the stream, then only change the canopy closure value on that side of the stream when modelling post-harvest conditions.

Shade percent is measured in the field as described in section V.

For the modelling, **right** and **left** streambank are defined looking downstream. Topography may be used as part or all of the shade calculation.

Select ***Left*** bank, hit return, enter the percent shade followed by hitting the return key again. Repeat for the *right* bank. Once you have entered percent shade values for both banks return to the main menu.

*14.* Review the model input values shown on the main menu screen. If you wish to change any item simply use the arrow keys to select that item and enter the new value.

*15.* GENERATE REPORT. The model will display "*computing, please* waif."

The model will begin calculating the predicted stream temperatures. The predicted mean, maximum and minimum temperatures are provided as well as a determination of the acceptability of the maximum temperature.

*16.* If you want to print the detailed results, after making sure your printer is on, press the ***shift and Print*** Screen keys simultaneously.

The model results will be saved in a file, whether or not you look at them. The default tile name is TFW_TEMP.OUT. Additional model runs will be added to the end of the file. Hourly temperature values predicted by the model will be stored in a file named TFW_HOUR.OUT. The file containing the hourly predictions is overwritten each time you run the model. These output files can be imported into a data-processing program if desired.

NOTE: You may want to occasionally delete or move the file named TFW_TEMP.OUT. To delete this file **type del tfw_temp.out** when at the dos prompt ***drive:\\.***

17. Review the results to make sure they are reasonable, and consistent with local knowledge of the site. Compare the air temperature profile used and groundwater flow rates to local knowledge of the site.

18. The model will ask you *if you wish to model the same site, but add a safety factor*.

    Type Y for yes or N for no.

    This option increases the air temperatures used in the model to above average. This option should NOT be used without some justification that higher air temperatures may truly be present.

19. The model will then describe how to evaluate the predicted change in temperature resulting from the proposed timber harvest. Follow the instructions carefully on this screen to determine the proper management action.

20. The model then returns to the main menu. The input values from the latest model run are retained by the model during a session. You may change any or all of the input values to generate another report.

## SECTION V FIELD MEASUREMENTS

### 5.1 Measuring Percent Shade

Field measurements of pre-harvest shade percentages, and estimates of post-harvest shade percentages, will be required during the testing phase of the T/F/W Temperature Method. It may be possible to use regional estimates of shading levels in the future once adequate information on riparian shading levels in Washington forests is analyzed.

Shade (synonymous with canopy closure in this report) may be estimated in several ways. Three possible methods are presented here.

**Use of a forest densiometer.** To measure canopy closure (percent shade) using a densiometer, hold the instrument at elbow height, 12 - 18 inches in front of body, parallel to the ground while standing in the middle of the stream inside the RMZ. The exact point along the stream to stand is dependent on the variability of the RMZ. If canopy closure is consistent along most of the entire RMZ then a single estimate is probably adequate. If canopy closure percentage differs along the distance of the RMZ, the average of several measurements taken at different points along the stream channel can be used. The average canopy closure can be a simple one, or a weighted average based on the length of stream within the RMZ represented by each densiometer reading.

For each estimation of canopy closure along the RMZ take a densiometer reading in all four cardinal directions and then average them. For pre-harvest conditions, use this average for both the left-and right-bank closure estimates. In cases where there is a noticeable difference in canopy closure along the left and right bank you will need to take separate measurements of canopy closure for each bank. In this case take a single densiometer measurement while facing each of the two banks. Use only the half of the densiometer sphere nearest the streambank in question.

**Using a visual estimate:** Shade can also be estimated visually. Select measuring points similar to above. While standing at the center of the stream, estimate the percent of sky blocked from view within a cone from a 30 degree angle from level to directly overhead. Do this for both streambanks.

The center of the stream is defined as the center point of the wetted perimeter along a line perpendicular to streamflow. Ignore areas of standing water not connected to the main flow when defining the center of the channel.

**Estimating shade based on forest angle:**

NOTE: This method is experimental and has not been fully verified. It should NOT BE USED WITHOUT BEING CONFIRMED BY A SECOND METHOD. It is included since it may be valuable for testers to evaluate this method during the management trials.It may often not be possible or be inconvenient to measure shade while standing in the middle of the stream. Table 5.1 provides estimated canopy closure values corresponding to the measured angle to the top of the canopy. Information contained in Table 5.1 was developed from the 1988 TWG temperature study (Sullivan and others 1990). A linear regression was made between shade and the angle formed between horizontal and the top of the canopy with the apex located at the center of the stream (fig. 5.1). The dependent variable was the canopy closure for the corresponding stream bank. Canopy closure was measured using a densiometer. Forty four sites throughout Washington were included in the analysis and the R squared value of the regression was 0.86. The standard error of estimate was 9.84. No regional distinctions were investigated. The angle to the top of the canopy when viewed from the far bank was calculated by its geometric relation to the angle measured from the center of the channel to the top of the canopy.

Use a clinometer or Abney level to measure the angle from a point on the opposite bank to the top of the canopy for the proposed RMZ. **Zero** equals no canopy. The measurement should be taken while standing at the edge of the ordinary high water channel with your feet at a comparable level to the summer low flow water surface (fig. 5.1). Find your measured angle in the center column of Table 5.1 and note the corresponding canopy closure value in the right hand column. Repeat this process for one representative point for every two hundred feet length of RMZ. If the RMZ is greater than 2000 feet, the measuring points may be placed farther apart with a total of ten measurements taken. If the RMZ is less then 800 feet in length, measure canopy closure at closer intervals for a total minimum of four measurements. If the top of the canopy is highly uneven additional measurements may be required. Note the canopy closure value listed in Table 5.1 for each measurement and calculate the average value for **use** in the temperature screen and model.

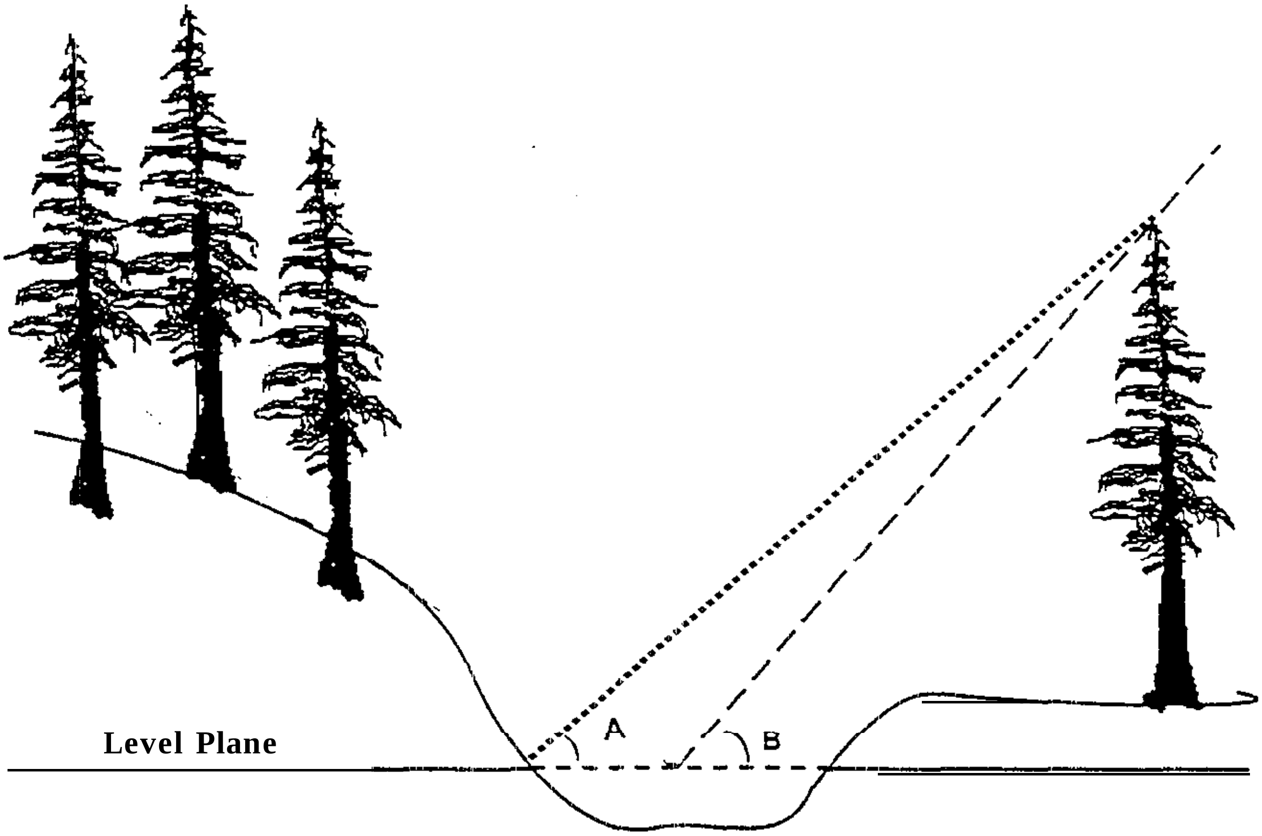



*Fig. 5.1 Estimating shade based on forest angle. The percent shade can be estimated as follows. Standing at the edge of the ordinary high water use a clinometer or abney* level to measure *the* percent slope to *the* top of *the canopy on the opposite bank (angle A). Find the value in the middle column* of *table 5.1 and note the corresponding percent shade. Note: This method is experimental* for *use in the management trials and should be compared regionally to values* of *shade measured with a densiometer for similar forest types.*

TABLE 5.1 ESTIMATING CANOPY CLOSURE USING A CLINOMETER

| Angle from midstream (percent) | Angle from far bank (percent) | Percent Shade |
|---|---|---|
| 30 | 16 | 8 |
| 35 | 20 | 14 |
| 40 | 24 | 21 |
| 45 | 29 | 27 |
| 50 | 33 | 33 |
| 55 | 37 | 39 |
| 60 | 41 | 45 |
| 65 | 44 | 52 |
| 70 | 47 | 58 |
| 75 | 51 | 64 |
| 80 | 54 | 70 |
| 85 | 57 | 76 |
| 90 | 60 | 83 |

## 5.2 Additional Field Observations

Additional field observations can be used to verity or update model input values. As previously described, shade is the most important variable to measure in the field.

Site elevation can be confirmed using an altimeter.

While in the field, note signs of groundwater flow rates. Are bogs, springs, or swamps frequent in the immediate area? If so, the stream may in fact be cooler than the model will predict, since the model uses an average value for groundwater inflow rate.

Single measurements of air temperature will be unreliable for modeling since it cannot be confirmed that they represent average conditions. However, a water temperature taken during the hottest part of the day for a hot summer day will provide a good indicator if the water quality temperature criteria is being exceeded for existing conditions. The water temperature at this time will equal the maximum equilibrium temperature. An explanation of this value is provided in section 2.1.

## SECTION VI DESIGNING THE RMZ

Shade is one of many factors that is considered when designing the riparian management zone. Wildlife needs and recruitment of large organic debris to the stream are some of the other concerns. In many cases, the normal design for the RMZ as specified in the forest practices manual provides sufficient shade to meet the water. quality criteria.

Figure 6.1 provides a guide for the percent shade required to meet the water quality criteria. As a general rule of thumb 50 - 7.5 percent shade will be required. Obviously this amount of shade may not be possible even under mature canopy conditions on larger streams.

Design the RMZ as you normally would to meet the forest practices regulations. All non-merchantable trees will be left and at least 50% of the existing shade will also be left. Additional shade may result from trees left for wildlife and from trees left in the RMZ to meet the minimum stem density. Estimate the amount of shade left with this proposed RMZ. Test this percentage of shade using the method described in section 3.4. If the shade is acceptable, you have completed the RMZ design with regards to stream temperature protection. If the methods described in section 3.4 indicate additional shade is needed beyond that provided in the normal RMZ design, select which additional trees will be left in order to meet the percent shade necessary to meet the water quality criteria. Estimate the additional shade contribution of these trees 'to the average shade value for the stream reach.

As an example, harvest along a 500 foot length of stream with 80% shade before harvest will result in 40% shade with a standard RMZ applied. The temperature screen, however, indicates that 60% shade is needed to meet the water quality criteria. You could provide an average of 60% shade by leaving all of the shade for 250 feet within the RMZ and reducing the shade to 40% in the other 250 feet. This would yield an average shade value of 60%. Distributing the shade throughout the RMZ to the greatest extent possible is recommended. Keep in mind that all other RMZ requirements are still in effect when designing the alternate RMZ. A densiometer will be especially useful for helping determine the relative contribution from individual trees to the overall percentage of shade.

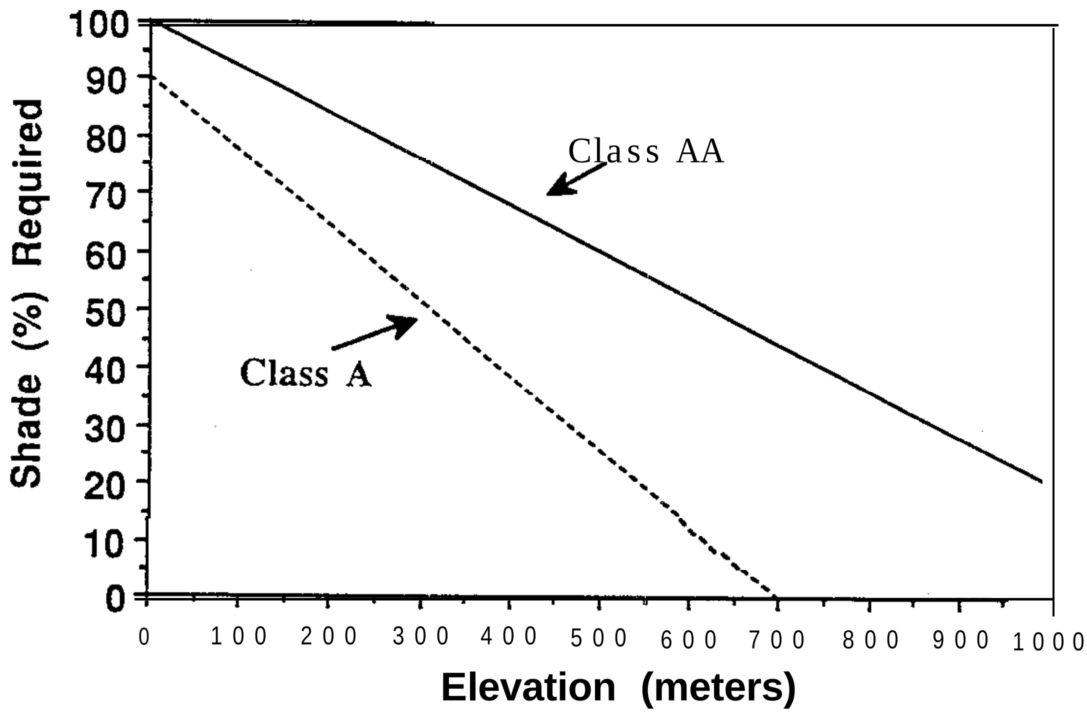



*Fig. 6.1 Shade requirements to meet the Washington Water Quality Temperature Criteria (WAC-173-201).*

## SECTION VII MONITORING AND FOLLOW UP

Recommendations for a statewide coordinated monitoring program are provided in the 1990 TWG Temperature Study Report (Sullivan and others, 1990). The coordination of those intending to monitor stream temperatures with the efforts of T/F/W Ambient Monitoring Committee and others is encouraged. This section of the manual provides suggestions on how to monitor stream and air temperatures as well as follow-up suggestions for reviewing the effectiveness of alternate RMZ's. Follow-up site visits to measure remaining shade and compare to intended shade percentages is important for effective management.

Managers may be interested in monitoring before or after timber harvest. Even single point temperature measurements on a hot afternoon indicate if the stream is likely to exceed the temperature criteria. Maximum/minimum thermometers are the simplest instrumentation available for monitoring water temperature. Their placement in the stream of interest for one day to several weeks between July 15 to August 15 will verify if the water temperature standards have been met. Maximum/minimum thermometers need to be securely fixed so that vibrations do not cause the recording pins to inadvertently move.

There are several manufacturers of continuous recording thermographs. Most of the newer equipment available reliably records temperature data in a computer format. If you intend to use the collected data for use with the TFWTEMP or TEMPEST model, you will need hourly temperature values. Many instruments allow a variable setting for frequency of recording. Some instruments allow the temperature to be sampled at a greater frequency than is recorded. Ideally, the temperature should be sampled at least every 15 minutes and an hourly maximum, mean and minimum recorded. Water temperature probes should be placed in a flowing section of the stream at a depth that is not likely to be de-watered as stream flow decreases. Avoid locating probes near seeps, springs, backwaters, and pools greater than four feet in depth. Air temperature probes should be placed at approximately three feet off the water or ground surface. A sun shield should be provided for air temperature probes. Instruments must be calibrated prior to deployment.

## SECTION VIII: FEEDBACK AND EVALUATION

### 8.1 Review of Methods

The TWG is suggesting the following avenue for feedback and evaluation of the temperature screen and TFWTEMP model. (Feedback on the actual effectiveness of the riparian regulations should be routed through the Water Quality Steering Committee, who is exploring this question under Project 7b of the CMER Workplan.)

A series of "Management Trials" will test the utility of the methods described in this manual. DNR is coordinating the management trials with the assistance of the T/F/W Field Implementation Committee and the Water Quality Committee. A plan for these trials is presented in Caldwell and others, 1991, a companion document to this report.

## 8.2 Screen and Model Updates

If the methods in this manual including the screen and TFWTEMP model are accepted for general use within T/F/W, it is expected that updates of the screen and model would be developed as required, as further information becomes available and regional and state-wide databases regarding stream characteristics and riparian shading values become available. The opening screen of the TFWIEMP model and the printed results from the model indicate the model version in use.

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## APPENDIX A. Air Temperature Profiles

| | Maximum Air Temperatures are: |
|---|---|
| Air Profile #1 | Less than 66°F |
| Air Profile #2 | Between 66.1°F and 69.6°F |
| Air Profile #3 | Between 69.7°F and 73.2°F |
| Air Profile #4 | Between 73.3°F and 76.8°F |
| Air Profile #5 | Between 76.9°F and 80.4°F |
| Air Profile #6 | Between 80.5°F and 84°F |
| Air Profile #7 | Greater than 84.1°F |

Each air temperature profile is a 31-day, hourly series of air temperatures, derived from measured data to reflect typical temperatures for July 15 through August 15, for seven classes of climate warmth. To check the model's choice of temperature profile, the user can take the best estimate of maximum (not average) air temperature, and compare this to the model's estimate.

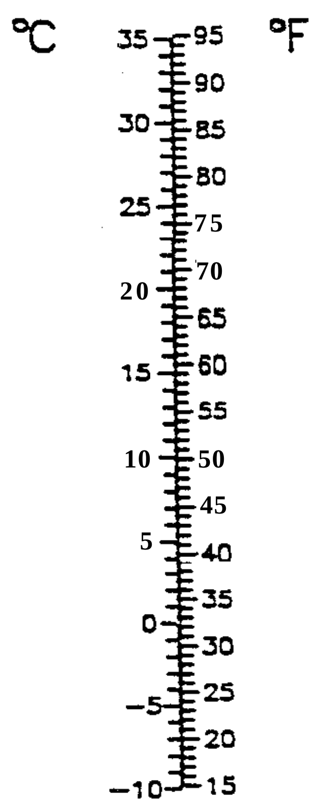
# APPENDIX B. Conversion Factors

## CONVERSION TABLES

| Multiply Metric Unin | BY | To Obtain English Units |
|---|---|---|
| Meters (m) | 3.28 | Feet (ft) |
| Kilometers (km) | 0.621 | Miles (mi) |
| Sq. Kilometers ($km^2$) | 0.386 | sq. Miles ($mi^2$) |
| CMS ($m^3/s$) (cubic meters per second) | 35.314 | CFS ($ft^3/sec$) (cubic feet per second) |

Degrees Celsius to Degrees Fahrenheit: $^{\circ}C = (^{\circ}F - 32)(0.55)$

Degrees Fahrenheit to Degrees Celsius: $^{\circ}F = (1.8)(^{\circ}C) + 32$



# APPENDIX C Water Quality Stream Classification

## Glossary of Terms

| | |
|---|---|
| Bankfull Width | Width of stream channel between the ordinary high water marks |
| Canopy Closure | The proportion of the sky that is screened by vegetation when viewed from the stream surface |
| CFS | Cubic feet per second, a measure of flowing water |
| Clinometer | Instrument that measures slope angle and height |
| CMS | Cubic meters per second, a measure of flowing water |
| CMER | Co-operative Monitoring, Evaluation and Research Committee |
| Densiometer | Instrument that measures amount of canopy closure |
| Distance from Divide | Measure of the distance between a particular site and the watershed divide |
| RMZ | Riparian Management Zone |
| TFW | Timber/Fish/Wildlife |
| TFWTEMP | Computer model, part of the Temperature Method |
| TWG | Temperature Work Group |
| View to the Sky | Amount of sky seen from stream level, inverse of canopy closure |
| WQSC | Water Quality Steering Committee |